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Introduction: The identification of lunar resources such as water is a fundamental component of the the NASA Vision for Space Exploration. The Lunar Prospector mission detected high concentrations of hydrogen at the lunar poles that may indicate the presence of water or other volatiles in the lunar regolith [1]. One explanation for the presence of enhanced hydrogen in permanently shadowed crater regions is long term trapping of water-ice delivered by comets, asteroids, and other meteoritic material that have bombarded the Moon over the last 4 billion years [2]. It is also possible that the hydrogen signal at the lunar poles is due to hydrogen implanted by the solar wind which is delayed from diffusing out of the regolith by the cold temperatures [3].

Previous measurements of the lunar atmosphere by the LACE experiment on Apollo 17, suggested the presence of cold trapped volatiles that were expelled by solar heating [4]. *In situ* composition and isotopic analyses of the lunar regolith will be required to establish the abundance, origin, and distribution of water-ice and other volatiles at the lunar poles. Volatile Analysis by Pyrolysis of Regolith (VAPoR) on the Moon using mass spectrometry is one technique that should be considered. **The VAPoR pyrolysis-mass spectrometer (pyr-MS) instrument concept study was selected for funding in 2007 by the NASA Lunar Sortie Science Opportunities (LSSO) Program**. VAPoR is a miniature version of the Sample Analysis at Mars (SAM) instrument suite currently being developed at NASA Goddard for the 2009 Mars Science Laboratory mission (Fig. 1).

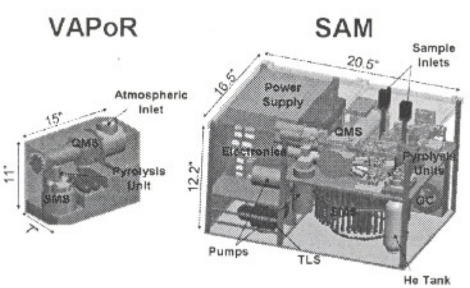

Figure 1. The VAPoR pyr-MS instrument will enable a detailed *in situ* characterization of lunar resources with reduced power, mass, volume, cost, and complexity compared to the SAM instrument suite.

Science Objectives: There are at least three key lunar science measurement objectives that can be achieved by the VAPoR instrument: (1) Measure the isotope ratios of carbon, hydrogen, oxygen, and nitrogen (CHON)-containing volatiles including water in polar regolith to establish their origin (see Fig. 2), (2) Understand the processes by which terrestrial organic compounds are dispersed and/or destroyed on the surface of the Moon to prepare for future human exploration and life detection on Mars, and (3) Measure the abundance of volatiles that can be released from lunar regolith for *in situ* resource utilization (ISRU) technology development.

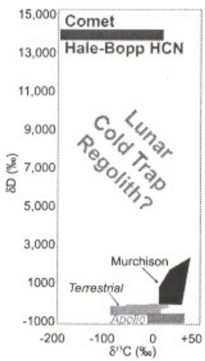

Figure 2. Isotopic analysis of water and other volatiles evolved from the lunar regolith by VAPoR can be used to constrain their origin(s). Solar wind implanted volatiles from the Apollo regolith, terrestrial organics, carbonaceous meteorite organics, and cometary volatiles show distinct H and C isotopic signatures. The nature and source of H in the polar cold trap regolith is unknown.

Future *in situ* investigations of a variety of locations on the Moon by VAPoR would help assess the organic contamination of the Moon by lunar spacecraft and humans [5]. There have been no direct *in situ* measurements of the lunar regolith to determine the extent of organic contamination of lunar soil samples prior to their return to Earth. Isotopic measurements of water, organics, and other volatiles would help distinguish terrestrial contamination from volatiles of lunar or exogenous origin. These studies would provide valuable "ground truth" data for Mars sample return missions and help define contamination and planetary protection requirements for future Mars bound spacecraft carrying life detection experiments.

Evaluation of ISRU related technologies will be of primary importance for future long term exploration of both the Moon and Mars. Laboratory studies on Earth of the Apollo lunar soils indicate that these materials evolve a variety of volatile gases including H_2, N_2, CO_2, CO, SO_2, and O_2 and the noble gases He, Kr, Xe, and Ar by heating the regolith under vacuum to elevated temperatures [6]. It is not presently known how the abundances of these volatiles vary over the surface of the Moon, or how much their concentration is enhanced in the polar cold trap regions. *In situ* measurements by VAPoR will enable an evaluation of the volatile content of the lunar regolith including water, oxygen and ^{3}He as well as their extraction efficiencies as a function of temperature. These studies would provide valuable data for ISRU technology development.

Instrument Concept: The VAPoR instrument suite will include a sample manipulation system (SMS) and vacuum pyrolysis unit, gas processing system, and mass spectrometer; all developed components of SAM. The resource requirements for VAPoR (mass: 7-15 kg; power: 18W avg, 36W peak; volume: 8"x17"x20"; telemetry rate: 4 kbps) are estimates based on the SAM pyrolysis mass spectrometer instrument and previous flight QMS instruments designed and built at GSFC.

Lunar regolith surface or subsurface samples could be delivered to the VAPoR instrument solid sample inlet robotically by a lander/rover scoop or drill, or collected and delivered to the inlet by an astronaut. The VAPoR SMS consists of a 6-cup exchangeable carousel mechanism designed to receive lunar regolith samples and heat the samples to elevated temperatures. Vacuum pyrolysis at temperatures up to 1400°C has been shown to be an efficient way to release volatiles from lunar regolith [6]. Development and testing of a vacuum pyrolysis system here at Goddard has shown that O_2 can be released from lunar analog materials under vacuum at temperatures above 1200°C [7].

The VAPoR gas handling system does not require pumps or carrier gases for the analysis of lunar volatiles. Atmospheric samples can be introduced directly into the mass spectrometer ion source through the atmospheric inlet by molecular diffusion. For solid samples, evolved gases are introduced into the gas processing system prior to mass spectrometer analyses. A scrubber made of CaO can be used to remove CO_2 and CO from the gas stream which is important for N_2 isotope measurements. In addition, a separate chemical getter will be used to efficiently remove active gases such as N_2 from the gas volume, which will enable enrichment of noble gases and methane required for higher precision isotope measurements. After saturation both of the getters can be regenerated *in situ* by heating to 900°C.

Following gas processing, enriched volatiles are introduced into the mass spectrometer ion source direct inlet via molecular diffusion. A quadrupole mass spectrometer for the SAM instrument suite is currently in fabrication and test at GSFC. An identical design could be used for VAPoR within the resources of the current concept. Mass spectrometers can detect a variety of volatile species released from lunar regolith by vacuum pyrolysis including water, hydrogen, carbon dioxide, nitrogen, sulfur dioxide, and oxygen over a large dynamic range as demonstrated by the VAPoR breadboard instrument developed at GSFC (Fig. 3). Highly miniaturized Micro Electro Mechanical Systems (MEMS)-based time-of-flight mass spectrometers (TOF-MS) are also currently under development at GSFC. could the MEMS-TOF-MS will enable a significant reduction in mass and power compared to traditional quadrupole mass spectrometers with a much higher mass resolution that will enable enhanced volatile separation capability and higher precision isotopic measurements.

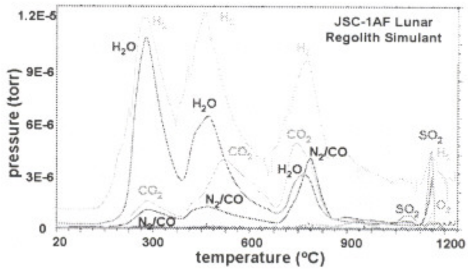

Figure 3. Critical in situ volatile measurements near the lunar poles can be accomplished by VAPoR as shown here. Above: VAPoR breadboard mass spectrometer analysis of water and other volatiles released from lunar regolith simulant (JSC-1AF) after heating to 1200°C under vacuum.

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